Urban Surface Modification as a Potential Ozone Air Quality Improvement Strategy in California

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Contractor Project Manager: Dr. Haider Taha
Commission Project Manager: Marla Mueller
Commission Contract Manager: Marla Mueller

The Issue

The term *urban heat island* refers to an urban area that absorbs and retains solar and man-made heat more efficiently than its rural surrounds. Urbanized regions can generate their own climates, with higher temperatures and associated meteorological conditions.[1] This heat island effect can result in additional summer cooling requirements (which raises energy demand) and increased precursor emissions and ground-level ozone (smog) formation.[2]

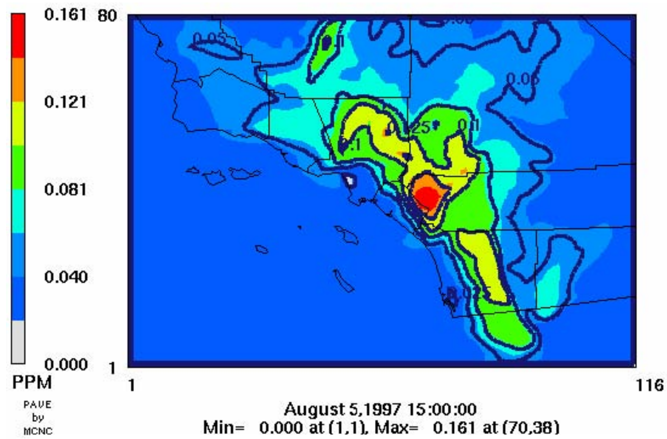

Figure 1. Simulated base-case ozone concentrations for Southern California at 1500 LST on August 5, 1997. The simulated peak is 161 ppb, slightly southwest of Rubidoux-Riverside.

The Los Angeles metropolitan area is an example of an urban heat island. Since the 1940s, as the region has become more urbanized, temperatures in that area have increased by about 6ºF. The economic effects are startling. One study estimated that the increased cooling necessary to counterbalance the heat island effect in Los Angeles costs local ratepayers $100 million each year.[3]

The effects of urban heat islands on local air quality can also be significant. Smog is formed by chemical reactions between nitrogen oxides (NO_X) and volatile organic compounds (VOC) in the presence of sunlight and heat. The higher the temperature, the more likely these compounds are

[1] Taha, H. 1997. "Urban climates and heat islands: Albedo, evapotranspiration, and anthropogenic heat," *Energy & Buildings*, Special Issue on Urban Heat Islands, Vol. 25, No 2., pp. 99–103.
[2] Taha et al. 1998. "Impacts of lowered urban air temperatures on precursor emission and ozone air quality," *Journal of the Air & Waste Management Association*, Vol. 48, pp. 860–865.
[3] Rosenfeld et al. 1996. "Policies to reduce heat islands: Magnitudes of benefits and incentives to achieve them." *Proceedings of the 1996 ACEEE Summer Study on Energy Efficiency in Buildings*, Pacific Grove, California. (Also Lawrence Berkeley National Laboratory Report No. 38679.)

to react and form smog, which can cause and exacerbate respiratory problems. Los Angeles has reduced its incidence of smog substantially in the past couple of decades, but on hot and stagnant days, e.g., when temperatures exceed 95ºF, local concentrations of smog can still rise sharply.

If the temperatures of urban areas could be lowered, less electricity would be needed to power cooling systems and a corresponding reduction in power plant emissions would be expected; moreover, the rate of smog formation would be reduced. Thus, lowering urban air temperatures may be a cost-effective means of supplementing traditional pollution control strategies.

Field measurements and modeling studies have shown that urban surface and air temperatures can be lowered by modifying the physical properties of urban surfaces. This can be accomplished, for example, by (1) increasing urban vegetation cover and (2) increasing the *albedo*, or reflectiveness, of roofing and paving materials. The resulting energy savings for summer cooling have been quantified at both the utility and building scales. The potential regional effects on air quality, however, can presently be assessed only via numerical modeling[4,5] and are much more difficult to ascertain due to uncertainties in meteorological and photochemical models and input data, as well as the complex, nonlinear nature of the photochemical reactions that produce ozone. Previous studies have shown both positive and negative impacts, but differ in whether surface modifications to lower local temperature would result in an overall net benefit or liability for air quality. More extensive, detailed modeling is required to determine the net outcome for a given set of circumstances (location, specific surface modifications, weather conditions, etc.).

Project Description

The first phase of this project updated and applied state-of-the-science meteorological and air quality models and recent meteorological and air-quality/emission data to develop a scientifically sound modeling system for urban heat islands. To help ensure its usability, the modeling system was designed to support the needs and meet criteria of the U.S. Environmental Protection Agency (EPA), California Air Districts, and the California Air Resources Board (ARB).

The modeling used 200-meter LULC (Land Use and Land Cover) data from the United States Geological Survey and recent air quality and emission data from the 1997 Southern California and 2000 Central California Ozone Studies. Four airsheds were considered: the Sacramento Valley, San Francisco Bay Area, North and South San Joaquin Valley, and Southern California (Los Angeles Basin, San Fernando Valley, Antelope Valley/Mojave, and San Diego).

The meteorological modeling of selected episodes and domains for these airsheds was conducted with the latest generation of the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) MM5 model, which was updated and improved in this project. The model output from MM5 served as input to emission and air quality models. The MM5 meteorological results were also used to estimate the large-scale impacts of heat island control on energy use in California.

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[4] Taha, H. 1997. "Modeling the impacts of large-scale albedo changes on ozone air quality in the South Coast Air Basin." *Atmospheric Environment*, Vol. 31, No. 11, pp. 1667–1676.
[5] Taha, H. 1996. "Modeling the impacts of increased urban vegetation on ozone air quality in the South Coast Air Basin." *Atmospheric Environment*, Vol. 30, No. 20, pp. 3423–3430.

In Phase 1 of this project, emission models were used to update air pollutant emission rates to reflect changes in the simulated meteorological conditions, and account for both anthropogenic emissions (from human activities) and biogenic emissions (from existing vegetation and vegetation that could be planted to cool an area). For the air quality modeling component of this study, the CAMx (Comprehensive Air Quality Model with extensions) photochemical model was updated and used to simulate baseline conditions and various heat island reduction scenarios.

The modeling conformed as much as possible to the configurations, domains, and episodes used by the ARB and by California Air Quality Management Districts in their State Implementation Plan (SIP) demonstration modeling. Modeling results were converted into NO_X and/or VOC emission-reduction equivalence metrics that can be used to estimate the benefits of heat island control more directly. In addition, results were translated into EPA-recommended metrics that can be incorporated into SIP or related incentives in the future.

To bring broad-based expertise to this work, a Project Advisory Committee (PAC) composed of a diverse group of air quality professionals is guiding research, reviewing deliverables, evaluating benefits, and recommending ways to enhance benefits and strategies for communicating results and commercializing this project’s products.

PIER Program Objectives and Anticipated Benefits for California

This project offers numerous benefits and meets the following PIER program objectives:

- **Evaluating and resolving the environmental effects of energy production.** This project provides a sound basis for assessing the potential air quality benefits of heat island reduction and will provide the Energy Commission, ARB, and California Air Quality Management Districts with recommendations and a basis for adopting surface modification strategies. The improved models developed in this project will enable planners to compare different strategies and scenarios to identify the most effective combinations of surface modifications, as well as potential tradeoffs with other strategies (such as emissions controls), to help reach/maintain ozone attainment status.
- **Providing affordable energy services.** The surface modifications modeled in this project would reduce the need for cooling and air conditioning, and thereby reduce the energy bills of Californians in urban heat islands. A prior study found that the energy savings from changing roof reflectivity would amount to $35 million per year.[3]

Results

Phase 1 results show that surface modifications lower air temperatures near the surface and in the boundary layer, reduce emissions of ozone precursors (from power plants and other sources such as evaporative biogenic emissions), reduce some photochemical reaction rates, and change the mixing height and wind speed. Albedo modifications (e.g., different roofing materials) typically decreased temperatures more effectively than vegetation. A combination of albedo modifications and increased vegetation was also an effective strategy for reducing temperature.

Overall, the simulations suggest these meteorological changes have highly variable impacts on ozone concentrations. Findings suggested that surface modification strategies can have positive impacts, depending on the location, time, and level of modification. Peak ozone concentrations in Southern California increased during certain times of the episode studied, whereas in Central California, the peaks decreased consistently. In terms of average metrics, all regions experienced ozone reductions.

The second phase of this project will use a new generation of mesoscale (urbanized) meteorological models to improve current estimates of the positive and negative air quality impacts and determine the overall effects of various surface modification schemes. The research will include multi-episodic evaluations as appropriate and will address implementation-specific and city-specific modeling to account for actual urban growth plans, and fine-resolution urban canopy parameterization to capture the canopy-layer phenomena that influence the polluted boundary layer. The next phase of research will also develop and update morphological and urban-characterization input to the models.

Final Report

The final report for the first phase of this project, *Urban Surface Modifications as a Potential Ozone Air Quality Improvement Strategy in California—Phase One: Initial Mesoscale Modeling* (report number CEC-500-2005-128), is available at the California Energy Commission website at www.energy.ca.gov/pier/final_project_reports/CEC-500-2005-128.html. The final report for the second phase of this work, *Urban Surface Modifications as a Potential Ozone Air Quality Improvement Strategy in California—Phase Two: Fine Resolution Modeling*, will be available in late 2007.

Contact

Marla Mueller • 916-654-4313 • mmueller@energy.state.ca.us